Sound analysis to model weight of broiler chickens

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Abstract

The evolution of chicken weight during the commercial growing of broilers is important to understand growth and feed conversion ratio (FCR) of each flock. In commercial broiler production, farmers routinely weigh birds both manually and automatically. Manually measure the weights is time consuming and laborious, and only provides discrete estimates of flock weight with low time resolution. On the other hand, the continuous monitoring of chicken weight using sensors can provide real-time information on growth rate and FCR of the flock during the cycle, thus providing a way of improving the profitability by (1) early detection of deviations from expected growth trajectory, and (2) enabling farmers to better plan the marketing of birds at a specific weight to the processing plant. However, the “step-on weighers” used in commercial broiler farms are limited by the fact that the estimated weight is often not representative of the flock average. Previous studies have shown a significant correlation ($p<0.001$) between the frequency of vocalisation and the age and weight of broilers. The aim of that study was to identify a model that describes the growth rate of broiler chickens based on the frequency of their vocalisations. It is part of an overall goal to develop a Precision Livestock Farming (PLF) tool that assists farmers in continuously and automatically monitoring the growth of broiler chickens during the production cycle. In the present study sound was recorded in broiler houses throughout the entire life of the birds for five different commercial production cycles. For each cycle the peak frequencies of the chicken vocalisations were used to estimate the weight and then they were compared with the observed weight of the birds automatically measured using on farm

automated weighing devices. The identified model used to predict the weight as a function of the Peak Frequency (PF) confirmed that bird weight could be predicted by the frequency analysis of the sounds emitted at farm level, although accurate editing of the audio file is necessary to enable this discrimination. Even if the precision of the weighing method based on sounds investigated in this study has to be improved, it gives a reasonable indication regarding the growth of broilers. In conclusion, using broiler sounds to predict the weight is a promising method that might integrate and not replace the information provided by the automatic weighing scale placed in the broiler houses.

Keywords: Broiler, vocalisation, growth trend, frequency analysis, Precision Livestock Farming

Introduction

Poultry is one of the cheapest sources of animal protein in the world, and the global demand for poultry meat is growing every year (Tullo, Fontana et al. 2013).

The global food scenario is rapidly changing, and the human population is expected to grow throughout the rest of the century and will reach 11 billion people by the year 2100 (FAOSTAT 2015; Mountford and Rapoport 2015).

Genetic progress in broiler breeding has led to the selection of breeds with faster growth rate, reduced slaughter age and higher final weight than previously achieved (Rauw, Kanis et al. 1998; Aerts, Van Buggenhout et al. 2003). In fact, Havenstein et al. (2003a,b) estimated that genetics contributed 85-90% to the 6 fold increase in carcass yield during the last 50 years.

The breeding of fast growing birds has been based on hybrid genotypes reared in tightly controlled environments under high stocking density and with limited space for physical activity (Rauw, Kanis et al. 1998; Kashiha, Pluk et al. 2013; Rizzi, Contiero et al. 2013). Therefore, the genetic potential for growth can be compromised by poor environmental quality, poor management and excessive density, and these factors may also result in welfare issues with a major economic relevance for industry (Marchewka, Watanabe et al. 2013).

Monitoring key production indicators like growth rate and feed conversion ratio (FCR) can help farmers to make changes to management practices to increase the performance of current genotypes (Chedad, Aerts et al. 2003; Mollah, Hasan et al. 2010; Fontana, Tullo et al. 2015).

In this respect, monitoring the evolution of bird weight in a broiler house is an important part of modern broiler production (Aerts, Van Buggenhout et al. 2003; Rizzi, Contiero et al. 2013) improving the efficiency and profitability of the processing plant (Cangar, Aerts et al. 2006).

The average weight of the flock is generally evaluated either manually or automatically using samples of birds chosen at random within a poultry house. The manual measurement of the weight of a representative number of animals in a building is time- and labour-intensive, since building may hold up to 50k birds.

Today, many farms use “step-on scales” placed on the floor of the poultry house to automatically collect the average weight of the birds in the flock.

Even if the weighing system gives an accurate weight value each time a bird steps onto it, this is only representative of the birds that access the automated weighers and certainly not all the birds in the flock (Chedad, Aerts et al. 2003).

The accuracy of automated weighing is limited due to (1) the reluctance of heavy birds to visit the weighing scale (which requires the bird to climb up onto the scale) at the end of the production period (Chedad, Aerts et al. 2003) and (2) the walking ability of fast-growing broilers that decrease with age, reducing their mobility and willingness to move (Nääs, Paz et al. 2009). Moreover, sick, lame and very heavy birds reduce their locomotor activity, and extend the time periods spent in resting and lying behaviour (Tullo, Fontana et al. 2015). Therefore, while current automatic weighers reduce time wasted by the farmer they fail to continuously follow the growth trend of the whole flock, whilst simultaneously not estimating the weight of sick, lame and very heavy birds that are reluctant to move and to jump onto the automated scale.

One of the principal objectives of precision livestock farming (PLF) is to develop automatic on-line monitoring tools (Guarino, Jans et al. 2008) to monitor animals’ behaviours and their biological responses in an accurate way (Tefera 2012; Fontana, Tullo et al. 2015). The application of sound analysis techniques has been widely studied (Montevecchi, Gallup et al. 1973; Marx, Leppelt et al. 2001; Feltenstein, Ford et al. 2002) to measure and analyse the amplitude and frequency of animals sounds (Moura, Nääs et al. 2008); and it is perceived that automated animal monitoring with images or sounds could potentially be used to support farmers in animal husbandry (Halachmi, Metz et al. 2002; Ismayilova, Costa et al. 2013).

Previous work has shown that the Peak Frequency (PF) of the sounds emitted by animals is inversely proportional to the age and the weight of the broilers (Fontana, Tullo et al. 2015).

However, a model that represents the evolution of PF in different commercial broiler houses was not identified. The analysis of sounds emitted by the animals, linked to their expected age and weight, might be used as an early warning method/system to evaluate the general status of the animals at farm level.

The aim of this study was to identify a model that describes the relation between the PF of broiler vocalisation and bird weight, and to explore the development of a tool capable of automatically detecting the growth of the chickens based on the frequency of their vocalisations during the production cycle.

Material and Methods

Model identification

In a preliminary study by (Fontana, Tullo et al. 2015), the aim was to record and analyse broiler vocalisations under farm condition to identify the relation between animal sounds and growth trends. In that study, a regression analysis was performed to predict the weight of the birds as a function of the peak frequency (PF= representing the frequency of maximum power) based on sounds collected in broiler houses of two commercial farms, one located in the UK and the other one located in the Netherlands.

The data collection was made during three production cycles, two in the UK (defined as Round 1 and Round 2) and one in The Netherlands (defined as Round 3).

The UK house dimensions were 61 x 21 m and the total floor area available to the birds was 1130m^2.

The Dutch house dimensions were 65 x 19 m and the total floor area available to the birds was 1235m^2. Around 28000 one-day-old chicks were placed in both houses in all the considered rounds.

The linear regression model identified was:

Weight = 2887.8 - 0.8861*PF (R^2=0.85) (1)

The animal growth trend is traditionally defined as a nonlinear function (Rizzi, Contiero et al. 2013); for this reason, in the present study, a polynomial regression (PROC REG) (SAS Institute 2012), was estimated based on the same dataset used to estimate the linear regression. The model used (weight = PF + PF^2) described the relation between growth trend and PF of broiler vocalisation.

Both regressions were compared in order to find the one that better fitted the data using AIC (Akaike Information Criterion) criterion and the R^2 values.Sound analysis was automatically performed using the Signal Processing toolbox of Matlab v2013. ?

Automated sound collection and analysis

To test the reliability of the polynomial regression, further sound recordings were made on the broiler farm located in The Netherlands during five production cycles (defined as Rounds 4 – 8). Sound recordings in these rounds were collected with the commercially available PLF sound monitoring system, previously developed for pig cough monitoring (SoundTalks®). This commercial system consists of condenser microphones shielded from the harsh environment (type Behringer C4) and a sound card (type ESI Maya 44). The microphones were phantom-powered with limited susceptibility to non directed noise, and were able to capture the sound from near-field sources, i.e. the animals directly beneath the recording microphone. The recordings were performed at 16-bit integer precision and with sampling frequency of 22.05 kHz (standard WAV file format). The sound card was placed in an embedded board (x64 architecture), running a GNU/Linux operating system. The system was monitored remotely through an internet wireless connection. The microphone was suspended from the roof of the broiler house at a height adjustable with a winch. For this experimental setup, the microphone was mounted at 1 m from the ground level. The recordings were continuous, with the audio data grouped into recordings of five minutes duration. All raw recordings were stored online on external hard drives for subsequent post processing (Hemeryck, Berckmans et al. 2015).

The entire data collection consisted of 42 days of recordings (24/7), resulting in 1008 h of recordings in total. In total, 29,700 audio files were used for the automated frequency analysis.

For the analysis, peak frequencies (PF) were determined for each 5-minutes duration raw audio recording. For each recording, a power spectral density (PSD) was calculated using Welch's method, which is an averaging approach to remove the influence of random noise on the spectra of stochastic signals. The PSD was calculated with a frequency resolution of 256 bins and an overlap of 50%, and the Hanning window minimised spectral leakage. The spectral content was transformed to a single sided representation, resulting in a linear frequency axis of 129 bins, ranging from 0Hz DC to to 11.025 kHz, each of them containing a PF.

For the PF determination of the broiler vocalisation, only frequency bins over 1,000 Hz were used, effectively filtering out any lower frequency noise to remove the ventilation and feeder lines noises.

Furthermore, the PFs automatically extracted were manually edited in order to avoid the influence of the outliers. Indeed, PFs out of the range of 1,100 Hz and 3,700 Hz were eliminated from the data set. In this way, the sounds automatically collected during the dark period (background noises, without vocalisations) were excluded from the analysis. This frequency interval was chosen since previous results showed that broiler vocalise in that frequency range (Fontana, Tullo et al. 2015)

Expected weight were estimated by applying the polynomial regression to PFs obtained.

Expected weights were then associated to the weights of broiler chickens automatically collect with a commercial “step-on scale", placed on the floor of the broiler houses. Weight data were continuously stored on an online server. The weights collected in conjunction with the days chosen for the sound analysis were included in the statistical analysis.

Correlation coefficients between expected and observed weight were estimated using the PROC CORR (SAS Institute 2012) in order to understand which prediction curve was the best to be used in the TTEST procedure (SAS Institute 2012). Furthermore, the AIC (Akaike Information Criterion) was used to estimate which prediction curve was the most accurate in predicting the weight. Observed and expected weights were compared with the TTEST procedure (SAS Institute 2012), first on the general trend and successively week by week.

Result and discussion

Model identification

Figures 1 show the linear regression found by (Fontana, Tullo et al. 2015) performed to predict the weight of the broilers as a linear function of the PF of the sounds (Hz) emitted by the birds.

The linear regression model identified was:

$$\text{Weight} = 2887.8 - 0.8861 * \text{PF} \ (R^2=0.85) \ (1)$$

The linear regression model resulted significant ($F = 90.90$, $P < 0.001$) and the R^2 indicates that the model accounts for 85% of the variation in weight.

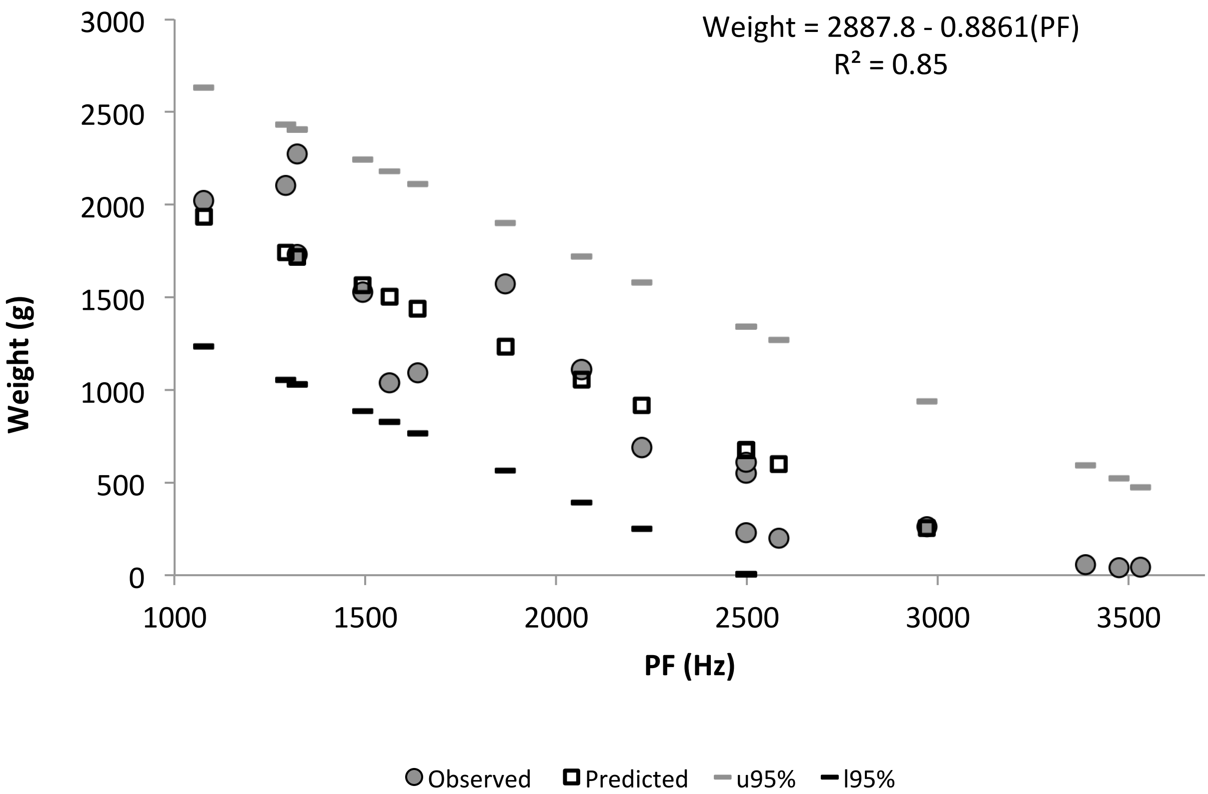


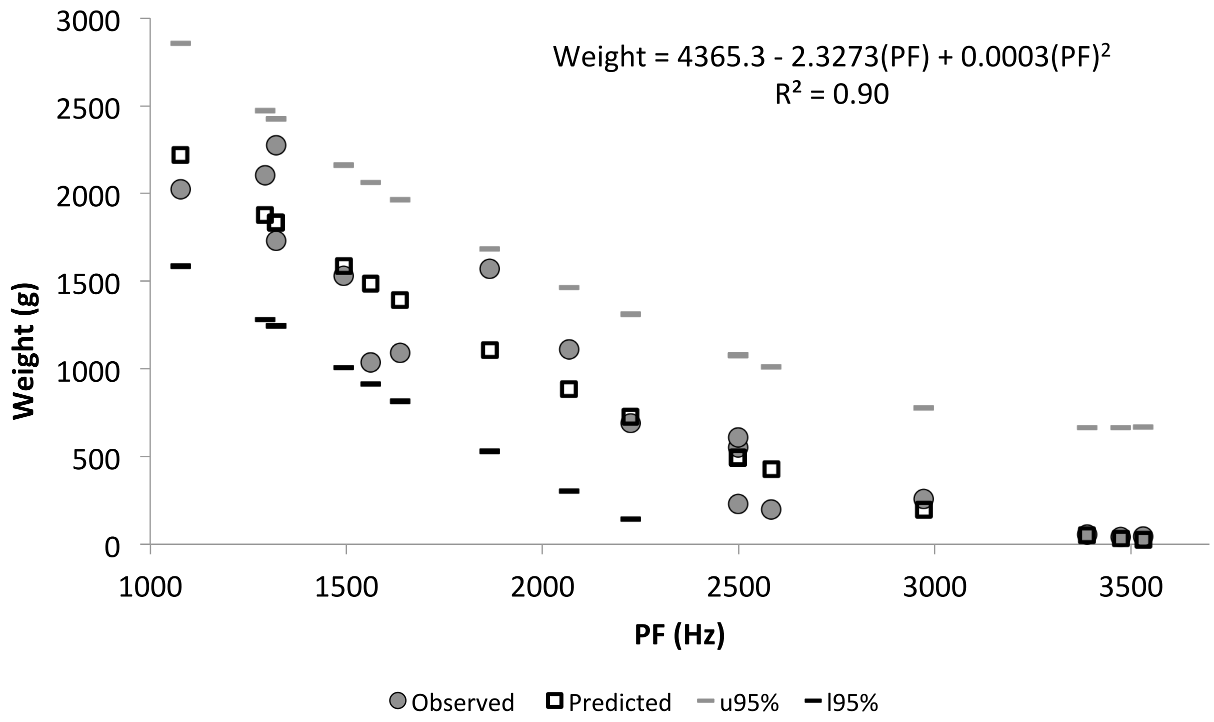
Figure 1. Linear regression to predict the weight of the broilers as a function of the PF emitted. l95% and u95% shows the 95% confidence interval of the observed values.

The polynomial regression model (Figure 2) was estimated based on the same dataset used to estimate the linear regression and resulted significant ($F = 67.31$, $P < 0.001$), indicating that the model accounts for a significant portion of variation in the data. The R^2 indicates that the model accounts for 90% of the variation in weight.

The identified polynomial regression model was:

$$Weight = 4365.3 - 2.3273(PF) + 0.0003(PF)^2 \quad (2)$$

where, PF was the Peak Frequency of the sounds (Hz) emitted by the birds.



Both regressions were compared in order to find the one that better fitted the data using According to the lowest AIC value (Akaike Information Criterion) and to the highest R^2 values the polynomial regression was chosen as the best weight predictive model that better fitted the data collected.

The regression coefficients were used to predict the broiler expected weight as a function of the PF for sound data collected and analysed automatically.

Automatic PF detection

Table 1 reports the PF values and the weights collected automatically during each round considered in the validation of the regression line. Datasets from the production rounds 6, 7 and 8 are not completed due to technical problems (loss of internet connection) which occurred during data collection. Sound data were recorded in real time and stored through the internet connection, for this reason, the lack of internet connection caused a considerable loss of data.

As it is possible to see in Tables 1 each age is characterised by its own typical peak frequency that decreases with the growth of the birds. Considering the difference between week 1 and week 6 it is

possible to see how the PF decreases of about 2000 Hz.

Table 1. Weekly mean and standard deviation of broiler weights (g) and Peak Frequency (PF) of their vocalisation (Hz).

Round	Week	Weight Mean (± s.d.) g	PF Mean (± s.d.) Hz
4	1	73.52 (± 14.49)	3216 (± 132)
	2	280.58 (± 34.36)	2900 (± 99)
	3	589.82 (± 54.36)	2412 (± 86)
	4	1000.76 (± 92.98)	2010 (± 50)
	5	1507.69 (± 105.05)	1665 (± 398)
	6	1894.33 (± 66.54)	1120 (± 0)
5	1	75.11 (± 15)	3244 (± 179)
	2	296.99 (± 48.54)	2871 (± 50)
	3	667.58 (± 54.92)	2412 (± 86)
	4	1148.38 (± 60.57)	1981 (± 0)
	5	1500.69 (± 71.26)	1665 (± 398)
	6	2064.19 (± 89.13)	1522 (± 99)
6	3	773.9 (± 351.07)	2498 (± 0)
	4	1141.72 (± 58.84)	1981 (± 0)
	5	1615.53 (± 77.33)	1809 (± 298)
	6	2511.03 (± 363.3)	1335 (± 61)
7	4	1108.19 (± 56.36)	2067 (± 0)
	5	1569.7 (± 35.86)	1838 (± 407)
	6	2039.76 (± 102.7)	1378 (± 149)
8	1	66.41 (± 13.31)	3330 (± 179)
	2	277.75 (± 44.51)	3043 (± 132)
	3	682.25 (± 68.43)	2412 (± 149)

Figure 3 clearly shows how the PF of the bird vocalisations during their life changes according to their age. At the beginning of the round, the peak frequencies were on average 3,263 ± 163 Hz, while by day 40, the average PF were 1,288 ± 75 Hz. Rounds 6, 7 and 8 were not complete due to internet connection problems on farm during the data collection.

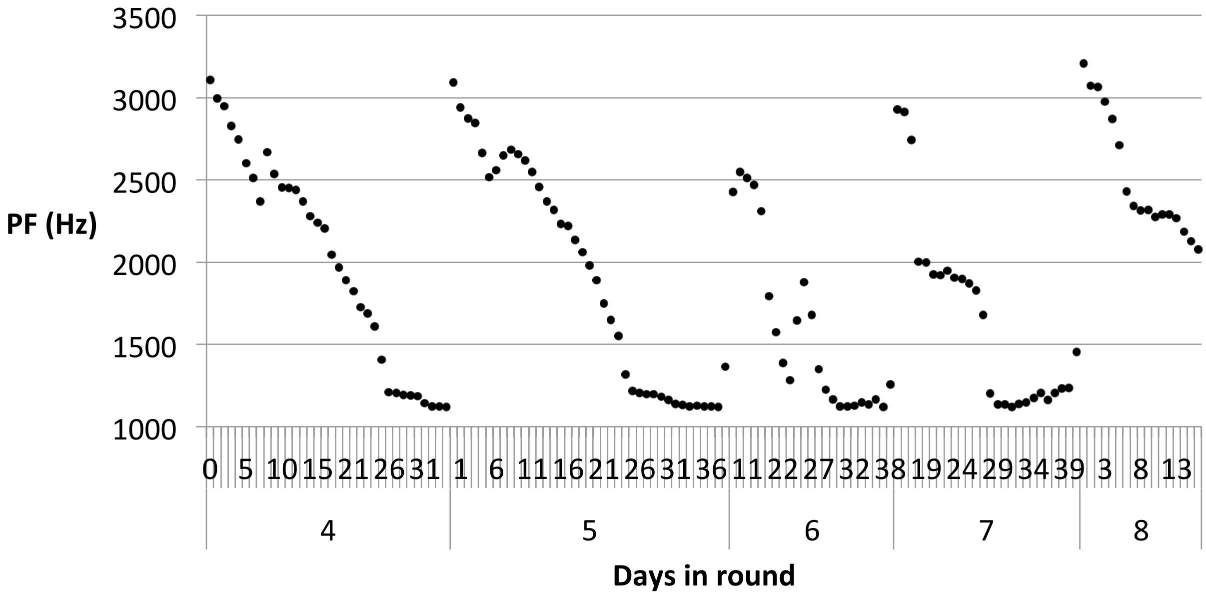


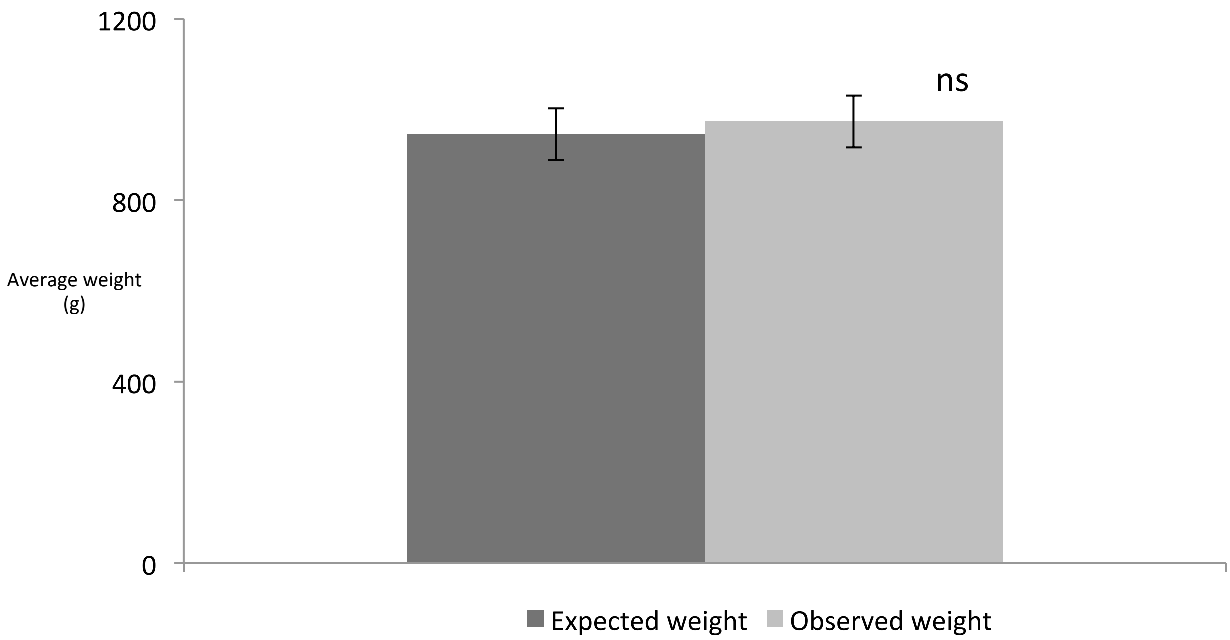
Figure 3. Peak frequencies trends during the five rounds with automated sound and weight data collection. Rounds 6, 7 and 8 were not complete due to internet connection problems on farm during the data collection.

Table 2 lists the observed and expected weights in weeks 1-6 calculated with the polynomial regression using the PF automatically extracted. The trend of expected and observed weights seems to be the same, but they differ in the last part of the rounds (week 5 and 6), due to the increase of background noise covering birds vocalisation. This trend was confirmed by the correlation coefficient between expected and observed weights that resulted high and positive (r=95%, p-value <0.001)

Table 2. Observed and expected average weights in weeks 1-6 calculated with polynomial regression using the PF automatically obtained

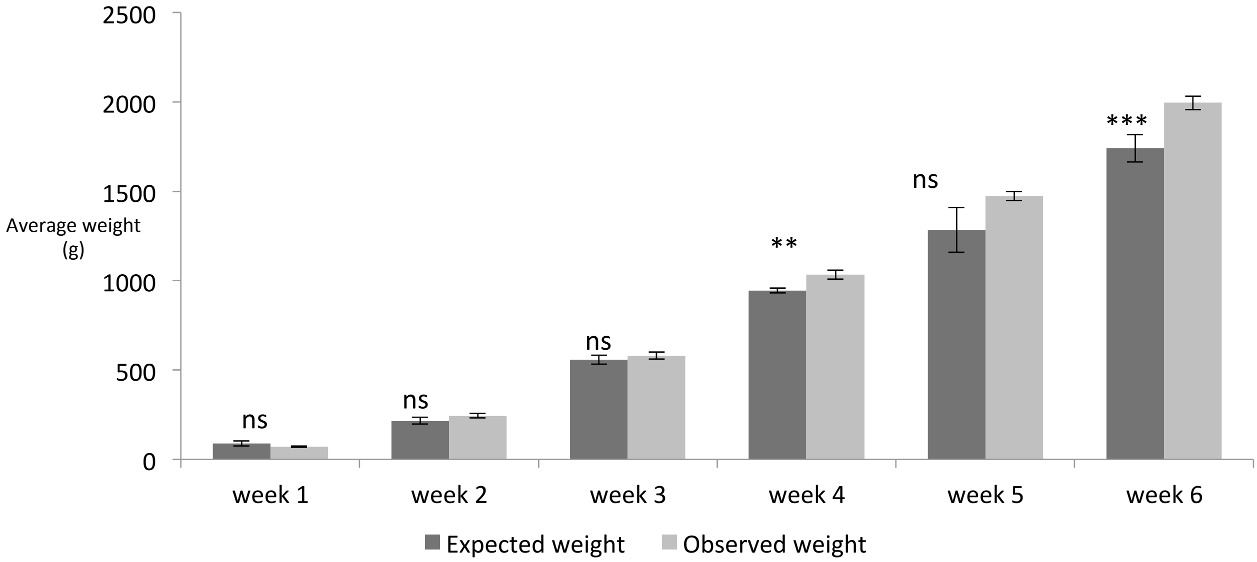
Week	Observed average weight (g)	Expected average weight (g)
1	71.68 (± 13.00)	89.17 (± 41.40)
2	243.97 (± 35.24)	216.24 (± 54.63)
3	580.59 (± 65.37)	556.99 (± 77.05)
4	1033.16 (± 86.80)	944.78 (± 45.30)
5	1474.06 (± 91.89)	1283.83 (± 436.2)
6	1994.94 (± 113.1)	1741.54 (± 231.6)

Figure 4. Levels of significance of the differences between observed and expected weights calculated with polynomial regression



***: P<0.001; **: P<0.01; *: P<0.05; ns: P>0.05

The TTEST procedure was performed to evaluate the general difference between observed and expected values calculated with polynomial regression. The results (Figure 4) show no significant difference between expected and observed weight.
However, when the TTEST procedure was performed on expected and observed weights week by week, the results were different (Figure 5). Indeed, considering the expected weights for each week of age as a separate value, the statistical difference varied considerably.



***: P<0.001; **: P<0.01; *: P<0.05; ns: P>0.05

Figure 5. Levels of significance of the differences between observed and expected weight performed week by week.

As reported in Figure 5, only expected weights on weeks 4 and 6 resulted in values which were significantly different from the observed ones.

The remaining expected weights were not significantly different from the observed values. This discrepancy between observed and expected values in the last weeks of production cycles could be ascribed to a number of causes. Firstly; lack of completeness in the data set considered, both for weights and PFs, could have negatively affected the results.
Secondly; It was difficult to detect precisely the PF during the last two weeks of the cycle production since the background noise in the poultry house overlapped the vocalisation sounds emitted by the birds. Both during the PF estimation and during the model validation it is hard to define a correct PF during week 5 and 6 of the bird’s life.
Thirdly; in this study, the peak frequencies were automatically extracted from 5 minute recorded audio files, and were modified by applying a filter to exclude frequencies below 1,000 Hz. The

combination of the filter applied and the high background noise during the last weeks might have prevented the identification of birds vocalisation PF.

Conclusion

The results of the present study confirmed how the PF of the sounds emitted by the broilers changes according to the age and the weight of the birds. However, the automated frequency analysis of the audio files will need to be improved for future developments of this process.

The results of this study indicate that the PF of the sounds emitted by the animals is inversely proportional to the age and the weight of the broilers. The model implemented to predict the weight as a function of the PF by frequency analysis of the sounds emitted at farm level was proven to be reasonably accurate, although a more accurate editing of the audio file is recommended. In this study we tested whether the automated recognition of PF of the vocalisation could be precise enough in predicting the weight of the broiler chickens, but seems that a more accurate extraction procedure would be needed in future iterations in order to reduce the difference between predicted and observed values.

A more accurate and precise automated PF extraction procedure, could be the basis for the creation of a comparatively accurate weight prediction algorithm based on sounds emitted by the broilers. However, up to now, the audio files have to be manually checked after performing the automated PF analysis, in order to have reliable results and so automation of this process would be required in future refinements of this concept.

Even if the precision of the weighing method based on sounds investigated in this study has to be improved, it gives a reasonable indication regarding the growth of broilers. In conclusion, using broiler sounds to predict the weight is a promising method that might integrate and not replace the information provided by the automatic weighing scale placed in the broiler houses.

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